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LARGE-TELESCOPE ALIGNMENT UTILIZING OPTICAL TOOLING TECHNIQUES

Glenville Rogers

Michigan University
Ann Arbor, Michigan

December 1969

Report of the Mount Haleakala Observatory

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NOTICES

__Sponsorship.__ The work reported herein is a part of the research under Project AMOS conducted at the Willow Run Laboratories of the Institute of Science and Technology for the Advanced Research Projects Agency, Department of Defense, under Contract DAHC-15-68-C-0144. Contracts and grants to The University of Michigan for the support of sponsored research are administered through the Office of the Vice-President for Research.

__Project Description.__ A primary objective of Project AMOS is the determination of the usefulness of ground-based optics for tracking and measuring the physical parameters of space objects. Other objectives include measuring geophysical parameters and conducting observation programs at the Mount Haleakala Observatory in selected areas of infrared astronomy. The Mount Haleakala Observatory is located on Kole Kole Peak, Mount Haleakala, on the island of Maui, Hawaii. The facility is operated by a staff of engineers, astrophysicists, and technicians, who maintain the station and conduct all long-term observations and experiments.

Project AMOS utilizes the capabilities of the Computation Department and of the Radar and Optics Laboratory of Willow Run Laboratories, as well as those of the Department of Electrical Engineering in the College of Engineering and the Department of Astronomy in the College of Literature, Science, and the Arts of The University of Michigan.

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Report of the Mount Haleakala Observatory

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GLENVILLE ROGERS

December 1969

Willow Run Laboratories
THE INSTITUTE OF SCIENCE AND TECHNOLOGY
THE UNIVERSITY OF MICHIGAN
Ann Arbor, Michigan

ABSTRACT

This report describes the alignment of a large astronomical telescope by the use of optical tooling techniques which are primarily based on the use of a standard-focusing aligning telescope, flat mirrors, and autocollimating procedures inside a closed dome. Because of ease of interpretation, this technique requires much less time than other alignment procedures.

The only stellar observations are those required to obtain residual pointing errors, which are correctable by the "indoor" techniques described herein.

The optical tooling method has been successfully used to align the 60-in. Mount Haleakala astronomical telescope. On autocollimation, "tilt" alignment of a 60-in.-diameter mirror can be read to 3 arcsec or 0.0009 in. across the diameter. This is more precise than the capability of most mirror support systems.

The techniques were also successfully applied to the two 48-in. telescopes at the Mount Haleakala Observatory.

CONTENTS

FIGURES

LARGE-TELESCOPE ALIGNMENT UTILIZING OPTICAL TOOLING TECHNIQUES

1 INTRODUCTION

This report is a detailed description of the techniques and equipment used in the mirror alignment of The University of Michigan, Mount Haleakala Observatory's 60-in. Cassegrain telescope, and a description of similar techniques used during the installation of a new declination-axis coupling between the two 48-in. telescopes (on a single mount), at the same observatory. These techniques are commonly used and referred to by many industries as "optical tooling." They are practiced extensively by aircraft and large-machinery manufacturers. Their successful application to large-telescope alignment is discussed in this report.

The technique was originally applied to the 60-in. telescope as an around-the-clock, "indoor" method of obtaining initial alignment that would be superior to the conventional methods involving multiple reflections of crossed-wires observed with the unaided eye. It permits reading the alignment of images (to a fixed reticle under magnification) to within 0.005 in. for centering and, frequently, less than 5 arcsec angle. Tilt of the 60-in.-diameter mirror (420-in. radius of curvature) was read to 3 arcsec (0.0009 in.) across the diameter.

Because a large precision flat mirror was not available for the autocollimation alignment of the primary mirror, it was decided to tentatively proceed with the best that was available: a plate glass mirror 36-in. square and 1/4 in. thick. This obviously precluded the resolution of the reflected reticle of the autocollimating eyepiece. However, by creating an aperture in the eyepiece, the reflected image was sufficiently resolved to align it with the eyepiece reticle.

Though limited by the above conditions, this initial alignment of the primary (within about 15 arcsec tilt) resulted in no detectable lack of star-image symmetry under the best atmospheric "seeing" conditions to date. Also, when the secondary mirror was aligned to the primary, the additional requirement of orthogonality (to 1/2 arcmin) between the optical axis of the telescope and the declination axis of the mount was easily accomplished.

Although the soundness of the technique was amply demonstrated, future alignments cannot rely on anything but a precision flat mirror for autocollimation of the primary if maximum precision is expected.

With all necessary equipment on hand, this alignment procedure, exclusive of mechanical modifications, took two men less than two weeks to complete. The short time required is clearly a decided advantage when mirrors are removed for realuminizing.

The rather complex description presented here is meant to be read or followed as a "cookbook" by the practical optical engineer.

2
ALIGNMENT OF THE 60-in CASSEGRAIN TELESCOPE

After installation of the primary and secondary mirrors of the 60-in. Cassegrain telescope at the Mount Haleakala Observatory, a means was required for readily aligning these two mirrors with each other on an axis that was orthogonal to the declination axis. An orthogonality condition of such accuracy is unusual for large optical telescopes.

The mount of this telescope is an equatorial arrangement on an azimuth turntable. It can be used as an azimuth-elevation system or the conventional polar-declination configuration. It can be controlled by a number of closed-loop servo systems for tracking conventional stellar and planetary objects. However, its primary control is by high-speed digital computer for the purpose of tracking low-orbit, zenith-transiting satellites.

The telescope proper is a conventional Cassegrain configuration with concave paraboloidal primary and convex hyperboloidal secondary mirrors. The telescope is focused by translating the secondary mirror by remote control.

The metal backplate of the primary cell is a ground surface with a number of screw-hole patterns suitable for mounting various experimental packages (sensors). This surface is the reference used for the alignment procedure. It is parallel to the declination axis within normal machining and assembly tolerances for instruments of this size.

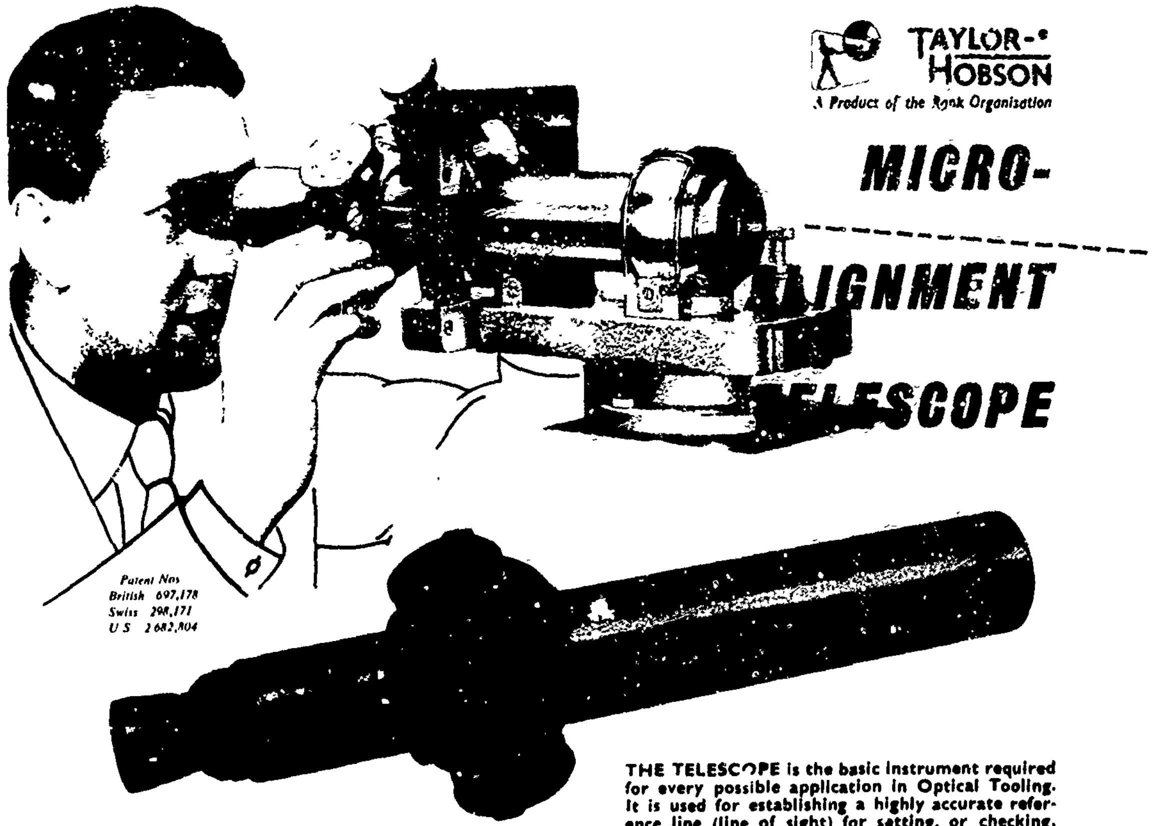
It is necessary to determine the variance from absolute parallel (to better than 1/2 arcmin) so that the alignment of the optical axis of the system can be set orthogonal to the declination axis within this limit. This limit is reasonable because any further refinement can be accomplished with adjustment of the data instrument. The focal length of the telescope is nominally 960 in. and this adjustment is less than 0.150 in., which is well within the field of best definition.

2.1. DETERMINATION OF REFERENCE

2.1.1. BASIC SETUP REQUIRED

To determine the relation of the backplate reference surface to the declination axis, a plane parallel flat mirror and two autocollimating telescopes with appropriate supports and mounts are required. Each telescope should be accurate to 5 arcsec or better (see fig. 1). The mirror should be a minimum of 4 in. in diameter, flat to a few fringes, with its two surfaces parallel within a few arcseconds.

The mount is oriented such that the telescope tube is horizontal and pointing east, also such that only the declination axis need be rotated 180° to point the telescope west, or vice versa (see fig. 2). This creates two positions in which the backplate is vertical and conveniently oriented for mounting and using a flat parallel mirror for autocollimation from the backplate ground surface. The angles of declination are 0° and 180° with the polar axis rotated to -90°. Parallel



THE TELESCOPE is the basic instrument required for every possible application in Optical Tooling. It is used for establishing a highly accurate reference line (line of sight) for setting, or checking, ALIGNMENT—PLANES—SQUARENESS.

Rank Taylor Hobson range of Telescopes includes the following:

	Code No
(a) MICRO-ALIGNMENT TELESCOPE	112/536 (English) 112/537 (Metric)
(b) MICRO-ALIGNMENT PROJECTION TELESCOPE	112/650 (English) 112/651 (Metric)
(c) ALIGNMENT TELESCOPE	112/538 (English) 112/539 (Metric)
(d) ALIGNMENT PROJECTION TELESCOPE	112/568 (English) 112/669 (Metric)

Alignment Telescopes (c) and (d) do not include Optical Micrometers

Specification and Performance Data (all telescopes)

MAGNIFICATION at Infinity Focus	× 34 with Standard Eyepiece. 43 with High Magnification Eyepiece
FOCUSING RANGE	Zero to Infinity
IMAGE	Erect
MICROMETERS (Telescopes (a) and (b))	Built in Optical Micrometers enable measurement of target displacement to Telescope line of sight in a direction at 90° to each other Range, ±0 050 in (±1,2 mm) in graduations of 0 001 in (0,02 mm) A click stop indicates zero reading
LOCATING TUBE	Hardened and stabilised steel Outside diameter 2 2495 — 2 2498 in (57,1373 57,1449 mm) Cylindrical within 0 0002 in (0,005 mm) Tube length 10-in (254 mm)
OPTICAL AXIS (Telescopes (a) and (b))	Concentric with and parallel to outside diameter of tube within 0 00025 in (0,0064 mm) and 3 secs of arc tolerance
OPTICAL AXIS (Telescopes (c) and (d))	(1) Zero to 5 ft. 1,5 metres). concentric to tube outside diameter within 0 001-in (0,025 mm.). (2) 5 ft. to infinity concentric with and parallel to outside diameter of tube within 0 0003-in (0,0076 mm) and 3 secs of arc tolerance
FIELD OF VIEW	2-in (50 mm) at 5 ft. (1 5 metres) 24-in (610 mm) at 100 ft (30 metres) Proportional for all other distances
OVERALL LENGTH	17 62-in (448 mm) nominal
WEIGHT (Telescopes (a) and (b))	10 lbs (4,5 kg)
WEIGHT (Telescopes (c) and (d))	8 lbs. (3,6 kg)
ACCURACY OF READINGS AND TARGET SETTINGS (Telescopes (a) and (b))	Within ±0 002 in (±0,05 mm) at 100 ft (30 metres) and proportionately for longer or shorter distances
ACCURACY OF READINGS AND TARGET SETTINGS (Telescopes (c) and (d))	Within ±0 003 in (±0,076 mm) at 30 ft (10 metres) and proportionately for longer or shorter distances
PROJECTION	Telescopes (b) and (d) incorporate a special projection graticule having thicker "cross lines" and centre annulus permitting projection up to 100 ft (30 metres) using Telescope Lamphouse 112/638 s
AUTO-REFLECTION and AUTO-COLLIMATION	All telescopes can be used for Auto Reflection and Auto Collimation using Telescope Lamphouse 112/638 s

All other equipment shown in this catalogue is accessory to the Telescope and its use will depend upon the nature of the work to be undertaken

FIGURE 1. MICRO-ALIGNMENT TELESCOPE. (This illustration is copied from page 2 of Taylor Hobson Brochure 303-49. Taylor Hobson is a division of the Rank Organisation, Leicester, England.)

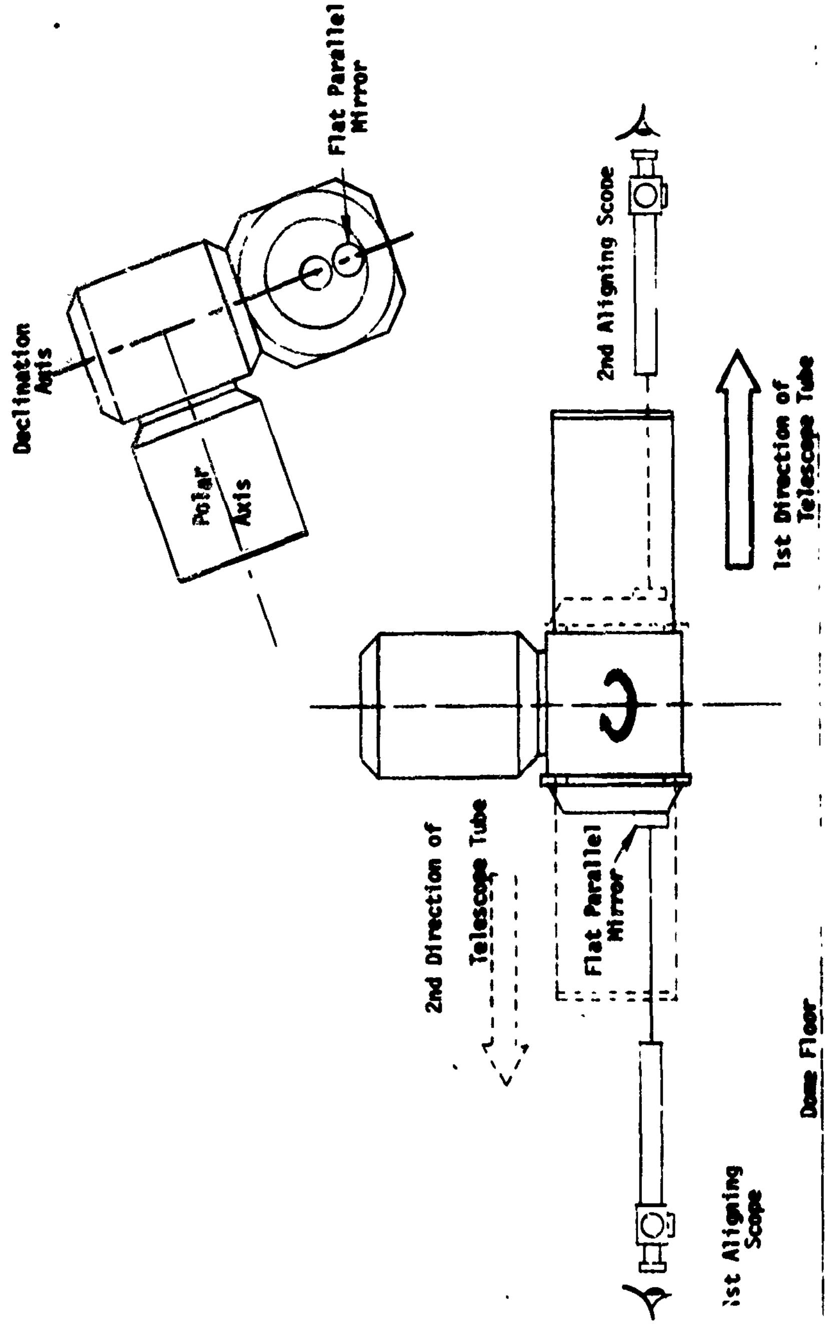


FIGURE 2. MEASUREMENT OF BASE PLATE ANGLE

to the axis of the horizontal telescope tube and facing each other from opposite sides of the dome are two autocollimating telescopes aligned with each other, only one of which needs a calibrated reticle.

2.1.2. PROCEDURE

The procedure followed is generally the same as in the above description except for minor variations for convenience.

First, the flat plane parallel mirror is mounted on the ground reference surface adjacent to the center hole through which the light beams form the Cassegrain image. In the telescope orientation mentioned above (fig. 2), the mirror should be on the lower side of the hole, opposite the polar axis and along the line of the declination axis. This is so that when the declination axis is rotated between 0^{o} and 180^{o} the height of the mirror above the floor does not change.

The two autocollimating telescopes are next set up on opposite sides of the dome, at the height of, and in line with, the plane mirror. One telescope is autocollimated off the plane mirror, centered on the reticle, and secured in position. The 60-in. polar axis is rotated sufficiently to create a clear line of sight between the two autocollimators. The second autocollimator is then aligned and centered with the first and secured in position.

Next the 60-in. polar axis is rotated back to its original position to achieve the original autocollimation and centering with respect to the first autocollimator. With the polar axis stationary, the declination axis only is rotated 180^{o} until autocollimation is achieved with the second autocollimator. The declination-axis rotation is halted when the moving image is midway across the field. The displacement of the moving image at right angles to its line of motion is the direction and measurement of the relationship between the reference surface and the declination axis. By rotating the declination axis back and forth between the two positions this measurement is rechecked. To be sure no misalignment of the two autocollimators has occurred between readings, the polar axis is rotated to verify their alignment with respect to each other.

In the case of the 60-in. telescope the backplate angle proved to be 3 arcmin, and in a direction such with the telescope tube parallel to the polar axis, a perpendicular to the reference surface would diverge from the polar axis in space.

2.2. ESTABLISHMENT OF TELESCOPE AXIS

2.2.1. ALIGNING TELESCOPE AND FIXTURE

When the angle and direction of the reference surface are known, the next procedure is to establish an offset from this surface to create an optical line of sight perpendicular to the declination axis. The aligning telescope illustrated in figure 1 is used for this purpose. Its features include the ability to focus from 0 in. to infinity, a reticle calibrated in 10-sec increments, autocollimation and autoreflection capabilities.

This aligning scope is placed in a fixture that fits the backplate reference surface of the 60-in. telescope. There are eight bolt holes in the 18-in.-diameter circle used to hold this fixture on the backplate. Two of these opposing holes were fitted with dowels to locate the aligning scope fixture to facilitate repetition. The aligning-scope fixture is fabricated from 1/2-in. steel with a ground surface to mate with the ground backplate. (See fig. 3.) It is basically "T" shaped with triangular bracing webs between the top and stem of the "T." Its center is an open tube with an appropriate ball socket at its upper end which precisely fits the aligning-scope barrel and screw-adjustment feature at its lower end to set the scope axis perpendicular to its ground surface. This was roughed in by autocollimating from a flat mirror against the ground surface.

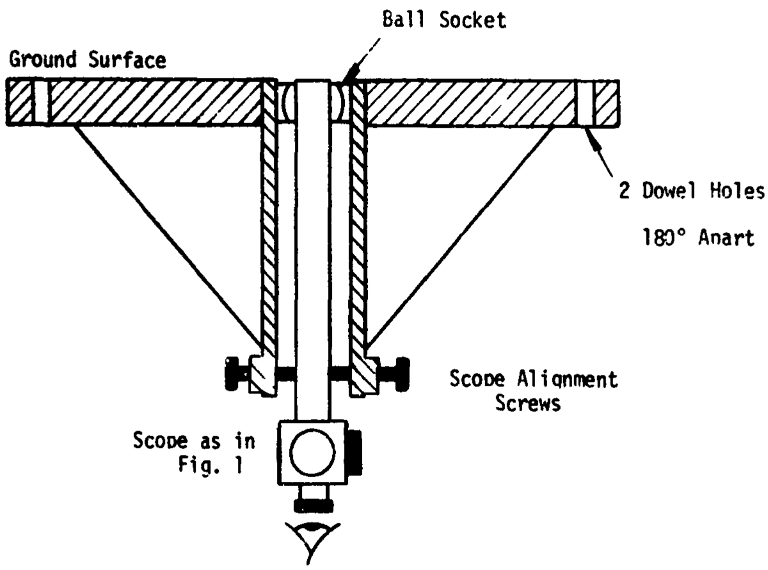


FIGURE 3. ALIGNING TELESCOPE IN ITS FIXTURE

2.2.2. FLAT-MIRROR INSTALLATION

The focal length of the 60-in. primary mirror is 210 in. The Cassegrain focus is 27 in. outside or beyond the primary-mirror apex and 12 in. outside or beyond the backplate reference surface.

A flat mirror is installed between the primary and secondary mirrors (facing the primary) for the following operations: first, in setting the aligning scope perpendicular to the backplate; second, for offsetting the aligning scope to establish a perpendicular to the declination axis; and third, to align the primary 60-in. mirror by autocollimation.

This flat mirror is mounted in a fixture which has adjustments for changing its angle relative to the telescope axis. Its position is 91.5 in. from the primary and 106.5 in. inside the main telescope tube, measured from the backplate. This dimension permits an autocollimating eyepiece to be used at the normal Cassegrain focus 12 in. from the backplate. (See fig. 4.) The light cone

diverging from the eyepiece is folded by the flat mirror back to the primary, a distance equal to the focal length of the primary: 12 + 106.5 + 91.5 = 210 in. It is thus projected parallel to infinity, then refolded back on itself by the flat mirror on the same paths to the autocollimating eyepiece reticle.

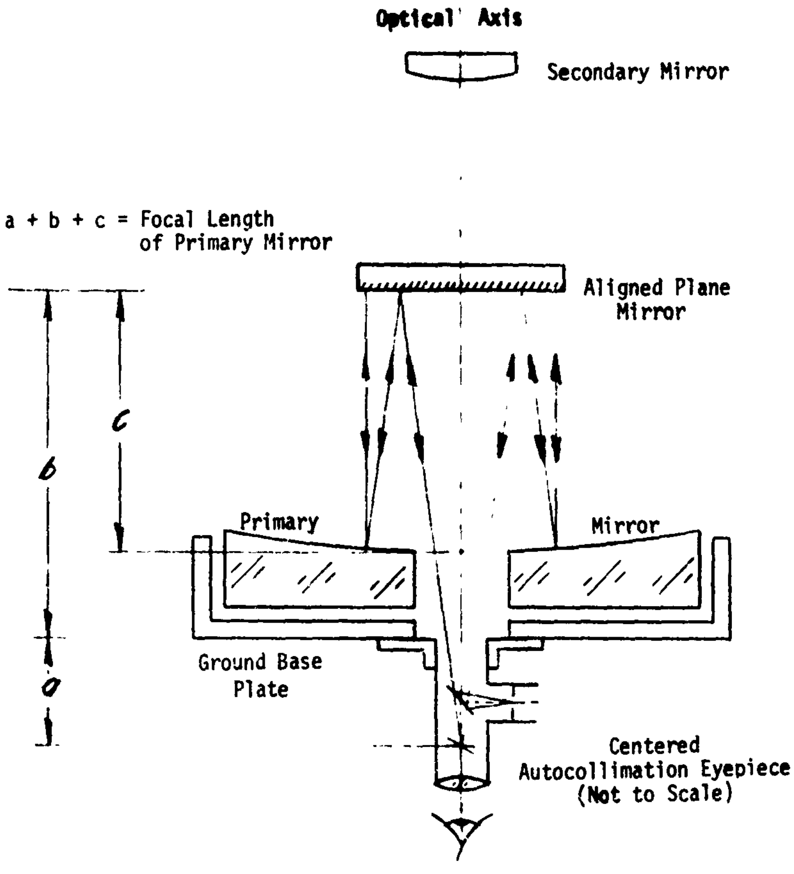


FIGURE 4. AUTOCOLLIMATION OF PRIMARY MIRROR

2.2.3. ALIGNMENT OF FLAT MIRROR

After the installation of the flat mirror, the 60-in. telescope is pointed to the zenith and the aligning scope (in its fixture) is fastened to the backplate. (See fig. 5.) The scope and mirror are aligned to each other as follows:

Since the aligning scope was roughly realigned in its fixture, the flat mirror is first "squared-on" with respect to the alignment scope by autocollimation and the reflected image centered. Without disturbing the adjustment of the aligning scope in its fixture, the fixture is removed from the backplate, rotated 180°, replaced on the dowels, and refastened. Any displace-

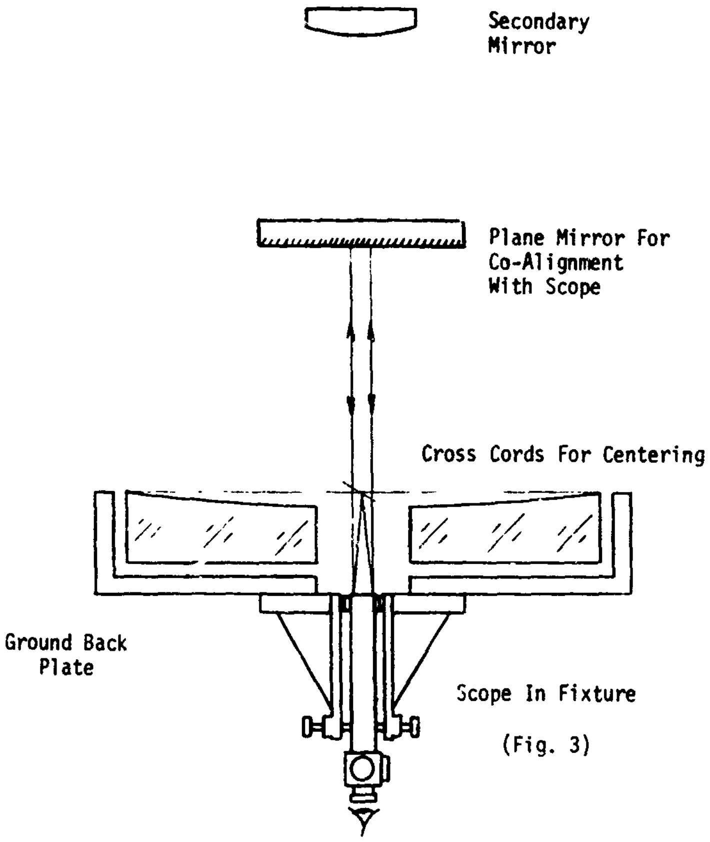


FIGURE 5. COALIGNMENT SCHEMATIC

ment of the reflected image in the eyepiece (relative to its original position) is an indication of the direction and the amount of nonorthogonality between the alignment scope axis and the backplate.

The aligning scope is then adjusted in its fixture to reduce the displacement of the reflected image to one-half while retaining the same direction of displacement. Without adjustment of the flat mirror, the aligning scope is rotated back to its original orientation. Any residual displacement is again reduced by half while retaining its same direction.

This process is repeated until the reflected image shows no obvious change in displacement at either orientation. Even though the reflected image may not be on center, its amount and direction of offset relative to the outside world should show no obvious change. When this condition is established, the flat mirror is adjusted to center the reflected image on the reticle of the aligning scope. The fixture and scope are once more rotated to verify coalignment of scope and flat mirror to the backplate.

2.2.4. ORTHOGONAL ALIGNMENT

After the angular difference between the backplate and the declination axis has been established, the aligning scope is offset this amount and in the proper direction. Then the flat mirror is readjusted to center the reflected image.

At this point a line of sight orthogonal to the declination axis has been established, and the flat mirror has been made perpendicular to that line of sight.

2.3. PRIMARY- AND SECONDARY-MIRROR ALIGNMENT

2.3.1. PRIMARY-MIRROR ALIGNMENT

On the assurance from the manufacturer that the "figure" of the primary mirror is sufficiently well centered within the mirror diameter, a pair of fine cords is used to create a cross at the mirror's center for alignment purposes. By focusing the alignment scope on this cross, the relation of the mirror center to the scope can be determined and the mirror centered to agree with the aligning-scope axis (see fig. 5).

The orientation of the fixture and aligning-scope combination on the backplate is marked for future reference of the offset direction. Without disturbing the scope alignment in the fixture, the combination is removed and stored carefully for a later operation in the alignment procedure.

Another fixture, similar to the aligning-scope fixture and fitting the same dowels and hole pattern, is mounted on the backplate. This fixture contains a centered hole that accepts an autocollimating eyepiece and positions its focus 12 in. from the backplate. It is adjustable axially for minor focus requirements.

At this point, only autocollimation by adjustment of its collimating screws is required to align the primary mirror. (See fig. 4.) The aligning telescope and fixture combination is replaced in its previously marked orientation, and primary-mirror centering is rechecked by observing the centering of the crossed cords.

2.3.2. SECONDARY-MIRROR ALIGNMENT

The flat mirror is now removed from the main telescope tube. With the aligning scope in place on the backplate, the alignment of the secondary can proceed. The first requirement is the addition of a pair of crossed cords designating the mechanical center of the secondary. Again we are assured by the manufacturer that there is no appreciable displacement of the "figure" with respect to the mirror diameter.

The aligning scope is focused on the cross and the mirror adjusted laterally to center it with respect to the aligning scope. The aligning scope is then refocused so as to form an image (of its reticle) reflected from the curved secondary to the aligning-scope eyepiece (see fig. 6).

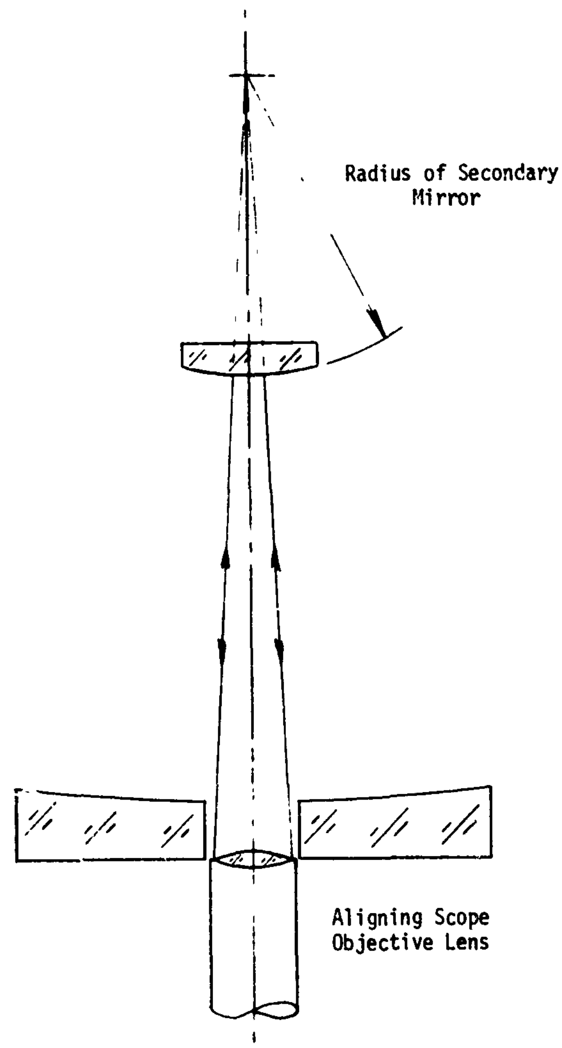


FIGURE 6. SCHEMATIC OF SECONDARY-MIRROR AUTOCOLLIMATION

Actually it is focused at a distance equal to the separation of the aligning-scope objective and secondary surface plus the radius of the secondary. In the case of the 60-in. in question, the separation was 15.2 ft and the radius of the secondary was 9.1 ft, giving a total of 24.3 ft which the focusing scale of the aligning scope indicated.

The tilting adjustment is now made to center the autocollimated image. The aligning scope is then refocused on the secondary cross for adjustment of residual centering error and residual tilt error is removed. This process is repeated until both centering and tilt errors are corrected.

2.3.3. VERIFICATION

The aligning scope in its fixture is removed and stored carefully until star observations have verified a symmetrical image, or until photographs (either Hartman or star field), have been made.

Finally, instrumental constants should be determined from stellar observations. This is a procedure involving a sequence of precise star observations to determine causes of residual inaccuracies in telescope pointing. It is useful in determining shaft-encoder offsets, structural flexure and errors in orthogonality of mount axes. The sequence involves four combinations of declination and azimuth orientations of 180° rotation. In principle, the procedure is the same as field checks for surveyor's transits or theodolites. Any data-acquisition package used with the telescope should have sufficient latitude of adjustment to reduce alignment errors to a limit commensurate with the field-of-view requirements of that instrument.

Should more stringent orthogonality be required, collimation error can be derived from the instrumental constants, set into the aligning scope, and the entire process repeated. Although this correction from instrumental constants was not required at Haleakala, I would estimate that, using the above alignment techniques and the correction, orthogonality to within 5 arcsec of the telescope flexure limits could be established.

2.3.4. SUMMARY

In the conception and design of future Cassegrain telescopes consideration should be given to incorporating the following features into the system to take advantage of the above alignment techniques.

(1) Maintain a permanent ground spot in the center of the figure of the secondary.

(2) Use autocollimation techniques, while the primary is being rotated on its polishing fixture, to provide a record of the relation between the figure and the diameter of the primary so that the primary can be properly oriented to the axis established by the aligning scope.

(3) Design the primary cell to provide a means of locating the aligning-scope fixture and the autocollimating eyepiece precisely on the optical axis.

(4) Provide a suitable plane mirror and a means to mount it at the appropriate distance between the primary and secondary telescope mirrors.

3
ALIGNMENT OF THE DUAL 48-in TELESCOPES

3.1. INTRODUCTION

By the use of optical tooling techniques, a pair of 48-in. astronomical telescopes mounted at either end of the declination axis of an equatorial mount was aligned and maintained in declination to a limit of 10 arcsec.

The original coupling between the two declination-axis shafts was designed to allow rotational adjustment of one shaft with respect to the other without inducing sideloading to the hydrostatic bearings. Unfortunately this type of coupling proved to be less rigid than required even though well designed for adjustment (fig. 7). The technique described in this report was first intended only to adjust the original coupling. During this process the lack of rigidity was observed and measured. It varied between 50 and 60 arcsec (see sec. 3.2.3 on rigidity test).

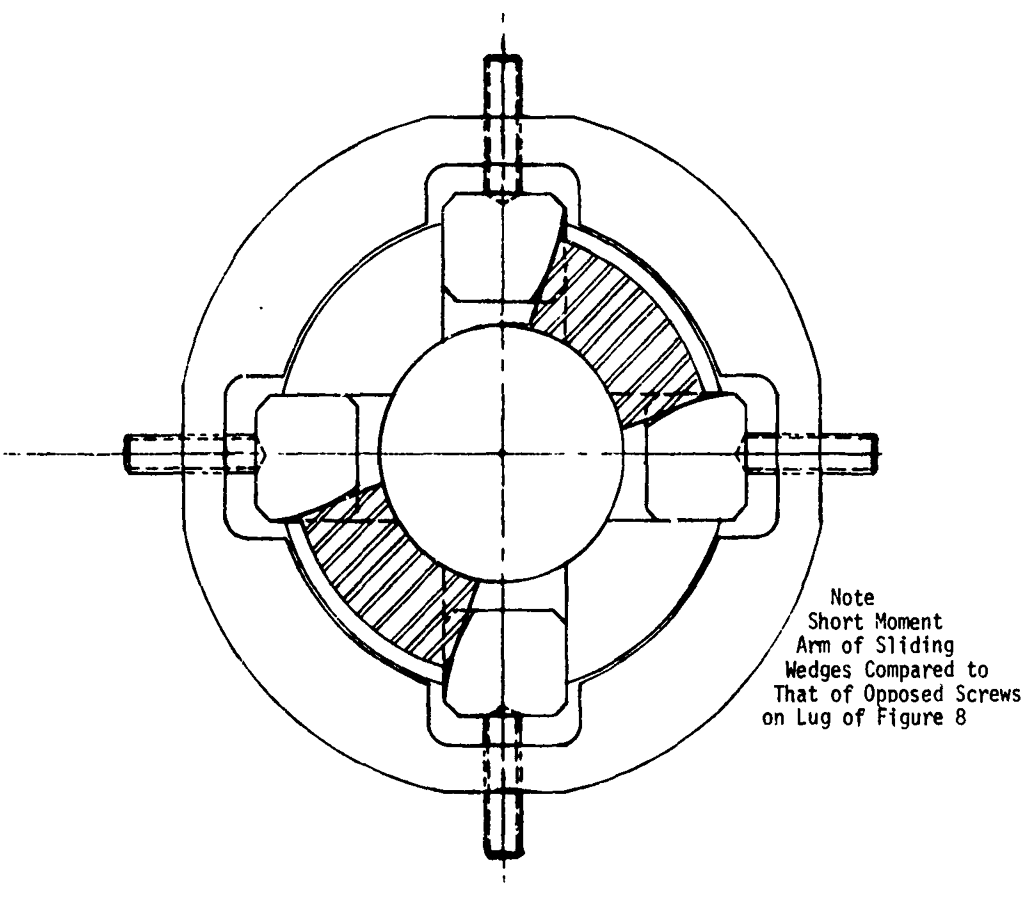


FIGURE 7. ORIGINAL COUPLING

A new coupling was designed on site and installed. It is larger and simpler than the original coupling. It derives its rigidity from the replacement of the sliding wedges of the old design with opposing machine screws that lock the two shafts in relation to each other (fig. 8). The only drawback to this design is that maladjustment can impart a lateral thrust to the shaft which will side-load the bearings. The alignment technique described here was conceived to avoid that possibility.

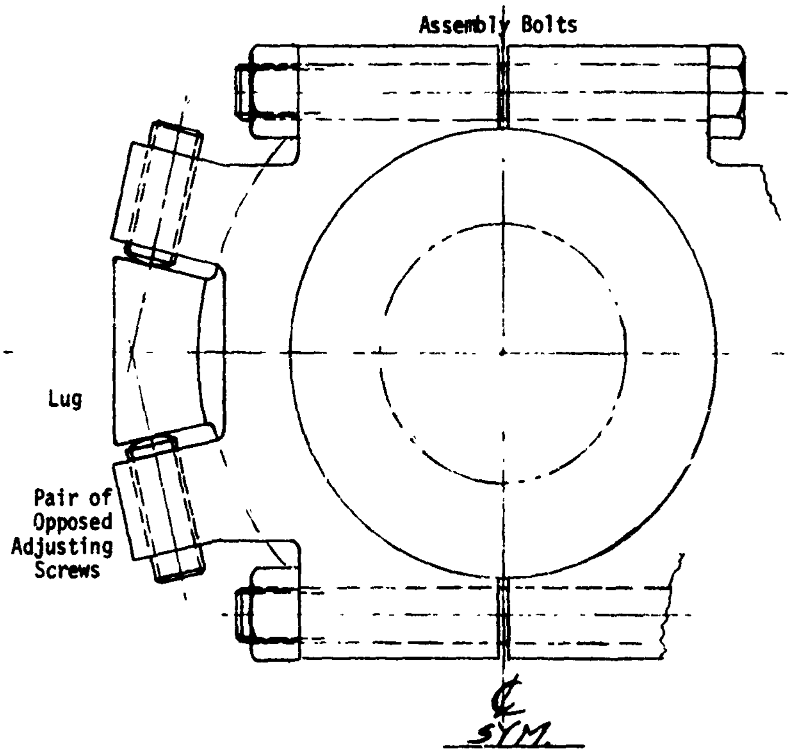


FIGURE 8. NEW COUPLING

3.2. COUPLING ALIGNMENT

3.2.1. BASIC SETUP

Each telescope at either end of the declination axis has its own hydrostatic bearing and is not dependent on the other for axial alignment. This feature allows the use of a simple coupling between the two shafts, for rotational adjustment only, and lends itself very well to the optical adjustment technique described.

When no hydraulic pressure is applied to the bearings, friction is great enough to immobilize the telescopes. Many hundred pound-feet of applied torque will not rotate the unpressurized bearing.

The telescope upon which the shaft-encoder inductosyn plates are mounted was used as the reference for the alignment.

3.2.2. PROCEDURE

The two telescopes were already aligned parallel to each other except for the lack of rigidity in the original coupling. They were pointed to the zenith with the polar axis at zero. This positions the declination axis in the horizontal. The hydraulic pressure was turned off, immobilizing the telescopes.

A small flat mirror was fastened to the backplate of the second telescope, which was to be rotated by the coupling adjustment. The mirror "faced" the dome floor. The autocollimating aligning telescope calibrated in 10 arcsec increments was mounted on the dome floor and autocollimated to the flat mirror. The reflected image was then centered.

At this point the original coupling was removed and the new one installed. The following description thus applies to both the original adjustment and any subsequent readjustment of the coupling.

The hydraulic lines on the second telescope form a tee that distributes pressure to each declination-axis bearing individually. The line which carries pressure to the reference-telescope bearing is disconnected at the tee and that side of the tee is capped. Hydraulic pressure will then "float" only the second telescope while the reference telescope remains fixed.

At this point observation of the reflected image in the aligning scope will reveal some rotation of the second ("floated") telescope: with both telescopes immobilized there is no "readout" of balance between the four coupling-adjustment-screw forces.

The lower pair of opposing screws are now backed out the maximum distance away from the "lug" which they normally hold in position (fig. 8). Observation of the aligning scope will probably indicate another rotation of the "floated" telescope. This can be in either direction, depending on which of the loosened screws was creating the greatest lateral thrust on the shaft.

At this point the "floated" telescope will be pointing in a direction controlled only by the opposing pair of screws acting on the upper "lug." In this condition the coupling cannot exert a lateral force on the shaft: it can only "hold" in rotation or move the telescope in rotation as desired.

The lower screws are left loose and the upper screws adjusted to rotate the "floated" telescope until the image seen in the aligning scope moves back to center. The two upper screws are tightened with maximum "hand" torque and locked with the locknut while maintaining "center" in the aligning scope. ("Hand" torque is the force of the unaided hand on a normal-length openend wrench.) To avoid any sideloading to the bearing, tightening and locking of both bottom

screws with maximum "hand" torque, without changing the position of the reflected image in the aligning scope, is critical.

As an illustration, (with both bottom screws backed out) it is suggested that one bottom screw in the second telescope be turned in until it touches its respective lug. A slight change will be observed in the aligning scope. Driving the same screw firmly will reveal a side shift in the bearing which may be indicated by as much as 20 arcsec rotation. By repeating this with the other bottom screw, similar rotation in the other direction will be observed. With only 0.002 in. clearance in the bearing, it is important that no sideloading should remain after final tightening of the bottom coupling screws. A uniform clearance in the bearings is essential for proper hydrostatic function.

The tightening procedure for the bottom screws is as follows:

(1) Note the initial aligning-scope reading of the reflected image with the bottom pair of screws (preferably adjusted to "0" center) not touching the lug.

(2) Tighten one screw sufficiently to read a few arcseconds' rotation (in the aligning scope) from the initial reading.

(3) Tighten the opposite screw to create a few arcseconds' rotation on the other side of the initial reading.

(4) Repeat this process with reduced amounts of overtravel (of the initial reading) as the screw torque increases. When maximum "hand" torque on the screws is reached and the locknuts have been tightened, the aligning scope should read the same as the initial reading (before the bottom screws were tightened).

3.2.3. RIGIDITY TEST

To check rigidity of the coupling, it is recommended that alternately directed torques be applied, sufficient to obviously deflect the "floated" telescope relative to the reference telescope. Satisfactory coupling performance will be observed when torque is removed and the rotation indication in the aligning scope returns to the initial reading. A ready means of creating alternating torque is to fasten a rope to either side of the secondary end of the telescope structure and have one man on each rope alternately pulling with a force of 50 to 100 lbs. Though this is a rather crude and rugged test, the coupling withstood it with no loss of adjustment. No change in the reference reading of the shaft-angle encoder was observed.

When the hydraulic line is reconnected, pointing differences of the declination axis should be determined and corrected before the setup is dismantled.

2.2.4. COMMENTS

The above test applies a minimum of 500 lb-ft of torque to the coupling. These telescopes are carefully balanced to drive equally well in either direction. Thus, although no measure of any residual opposing torque around the coupling shaft is available, the balancing technique precludes forces approaching the above figures.

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3 REPORT TITLE

Report of the Mount Haleakala Observatory: LARGE TELESCOPE ALIGNMENT UTILIZING OPTICAL TOOLING TECHNIQUES

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5 AUTHOR(S) *(First name, middle initial, last name)*

Glenville Rogers

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13 ABSTRACT

This report describes the alignment of a large astronomical telescope by the use of optical tooling techniques which are primarily based on the use of a standard-focusing aligning telescope, flat mirrors, and autocollimating procedures inside a closed dome. Because of ease of interpretation, this technique requires much less time than other alignment procedures.

The only stellar observations are those required to obtain residual pointing errors, which are correctable by the "indoor" techniques described ~~herein~~.

The optical tooling method ~~has been~~ successfully used to align the 60-in. Mount Haleakala astronomical telescope. On autocollimation, "tilt" alignment of a 60-in.-diameter mirror can be read to 3 arcsec or 0.0009 in. across the diameter. This is more precise than the capability of most mirror support systems.

The techniques were also successfully applied to the two 48-in. telescopes at the Mount Haleakala Observatory.

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